Claim Amendment

1. (Currently Amended) A spring surface treatment method, comprising the steps of:

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(A) nitriding a surface layer of a spring;

(B) projecting hard metal particles having hardness which is lower than the hardness of the nitrided outermost surface layer and is in the range of Hv 500 to 800 and diameters from 200 to 900 μm against the nitrided surface of the spring at a velocity from 40 m/sec. to 90 m/sec., so as to prevent generation of a microcrack in the surface layer by the projection and provide compression residual stress comparatively deep inside the springs; and

(C) projecting a number of fine metal particles having a mean diameter of all particles of 80 μm or less, a mean diameter of each particle in the range between l0 μm ~~inclusive~~ and ~~less than 100~~ 80 μm inclusive, a spherical or near spherical shape having no square portions, specific gravity from 7.0 to 9.0, and hardness which falls in the range between Hv 600 and Hv 1100 inclusive and is equal to or less than the hardness of the outermost surface layer of the spring after nitriding or low-temperature carbonitriding at velocity from 50 to 190 m/sec., while controlling an instantaneous temperature rise limit of an iron matrix excluding the nitride compound layer of the nitrided spring surface layer due to collision to be low enough to cause work hardening in the spring surface layer but not to cause softening due to recovery/recrystallization, thereby effectively work hardening and preventing generation of any microcracks in the surface layer to provide a high compression residual stress and hardness.

2. (Currently Amended) A spring surface treatment method, comprising the steps of:

(A) projecting a number of metal particles having diameters between 10 μm inclusive and less than 100 μm, a mean diameter of all particles of 80 μm or less, a mean diameter of each particle of 10 to 80 μm, a spherical or near spherical shape having no square portions, a specific gravity of 7.0 to 9.0, and a hardness of Hv 350 to 900 against a surface of a spring before nitriding at a collision velocity in the range of 50 m/sec. and 160 m/sec. inclusive so that a temperature rise limit of the surface of the spring due to collision is controlled to be low enough to cause work hardening of an iron matrix of the spring but lower than the point at which recovery/recrystallization may occur so as to prevent generation of any microcracks;

(B) nitriding a surface portion of the spring after step (A);

(C) projecting hard metal particles having hardness which is lower than the hardness of the nitrided outermost surface layer and in the range of Hv 500 to 800, and a grain diameter of 200 to 900 μm against the nitrided surface of the spring at a velocity of 40 m/sec. to 90 m/sec., so as to prevent generation of any microcracks in the surface layer by the projection and provide compression residual stress comparatively deep inside each spring; and

(D) projecting a number of metal microparticles having a mean diameter of all particles of 80 μm or less, a mean diameter of each particle in the range between 10 μm ~~inclusive and less than 100~~ <u>and 80</u> μm <u>inclusive</u>, a spherical or near spherical shape with no square portions, a specific gravity of 7.0 to 9.0, and a hardness which falls in the range between Hv 600 and Hv 1100 inclusive and is equal to or less than the hardness

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of the outermost surface layer of the spring after nitriding or low-temperature carbonitriding at the velocity of 50 to 190 m/sec., while controlling the instantaneous temperature rise limit of the iron matrix excluding nitride compound layer of the nitrided spring surface layer due to collision to be high enough to cause work hardening in the surface layer but lower than a point at which softening due to recovery/recrystallization may occur, thereby effectively causing work hardening and preventing generation of any microcracks in the surface layer to provide a high compression residual stress and hardness.

3. (Currently Amended) A surface treatment method, comprising the step of bombarding hard metal particles having hardness in the range between Hv 350 and 1100, specific gravity of 7.0 to 9.0, a mean diameter of all particles of 80 μm or less, a mean diameter of each particle in the range between 10 μm ~~inclusive~~ and ~~less than 100~~ <u>80</u> μm <u>inclusive</u>, and a spherical or near spherical shape with no square portions, on a surface of a spring with surface layer hardness of Hv 400 to 750, which hardness was obtained by one of low-temperature annealing for removal of macroscopic residual stress after cold forming, quenching and tempering after cold forming, and quenching and tempering after hot forming, at a collision velocity of 50 m/sec to 160 m/sec, while controlling the temperature rise limit of the spring surface layer due to collision to be low enough to cause work hardening in the spring surface layer but not to cause softening due to recovery/recrystallization and preventing generation of any microcracks in the surface layer which may deteriorate fatigue strength, thereby improving the hardness

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and compression residual stress of the surface layer which is 30 μm to 50 μm or less deep from the surface and resulting in improved endurance of the spring.

4. (Previously Presented) A spring surface treatment method for preventing generation of harmful microcracks in a surface layer of a spring which may deteriorate fatigue strength and for improving especially the hardness and compression residual stress of the surface layer which is 30 μm to 50 μm or less deep from the surface, to improve endurance of the spring, the method comprising the steps of:

(A) projecting hard metal particles having hardness of Hv 350 to 900 and a particle diameter of 200 to 900 μm against the surface of a formed and tempered spring having a surface layer with hardness of Hv 400 to 750 at a velocity of 40 m/sec to 90 m/sec so as to prevent generation of harmful microcracks in the surface layer and provide compression residual stress comparatively deep inside the spring; and

(B) performing the surface treatment method according to claim 3 on the spring surface after step (A).

5. (Previously Presented) A spring surface treatment method according to claim 1 or 2, wherein the particles projected in step (C) of claim 1 or step (A) of claim 2 and the projection conditions of the particles are limited to the following:

hardness of projected particles: initial hardness being Hv 600 to 1100;

size of projected particles: initial mean diameter of each particle being 10 μm to 80 μm;

mean diameter of all particles: 65 μm or less;

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specific gravity of projected particles : 7.0 to 9.0; and

collision velocity against the spring: 60 m/sec. to 140 m/sec.

6. (Previously Presented) A spring surface treatment method according to claim 3 or 4, wherein the particles used to bombard the spring surface and the projection conditions of the particles are limited to the following:

hardness of projected particles: initial hardness being Hv 350 to 1100;

size of projected particles: initial mean diameter of each particle being 10 μm to 80 μm;

mean diameter of all particles: 65 μm or less;

specific gravity of projected particles: 7.0 to 9.0; and

collision velocity against spring: 60 m/sec. to 140 m/sec.

7. (Original) A spring surface treatment method according to claim 1 or 4, wherein in the step (B) of claim 1 or in the step (A) of claim 4, the projection of the hard metal particles having a diameter of 0.2 to 0.9 mm is divided into first-stage projection of comparatively large particles having a diameter of 0.5 to 0.9 mm and second-stage projection of comparatively small particles having a diameter of 0.2 to 0.4 mm.

8. (Previously Presented) A spring produced from a circular cross-section wire or a non-circular cross-section wire by the steps according to claim 1 as essential steps, the spring being a coil spring made of any of steel types (1) to (4) containing respective chemical components, a compression residual stress of iron in a near surface layer by

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X-ray method being greater than 1700 MPa, sizes of a hard nonmetallic inclusion which may cause fatigue breaking of the spring and the hardness of matrix satisfying the following condition X or Y, the spring being a high fatigue resistance strength spring having a fatigue strength at 5×10^7 times of repetition satisfying expression (1) below:

in a repeated stress of $\tau m \pm \tau a$, when $\tau m = 800 - x$,

$\tau a \geq (620 + x/5)$ ------ (1)

where

τm is mean stress,

τa is amplitude stress, and

x is a variable in the range of 0 and 150 inclusive, and

all in the unit of MPa,

condition X: controlling the hardness of the matrix at a depth in the range of 0.2 mm to 0.5 mm inclusive from the spring surface in the range between Hv 520 and 580 inclusive when the size of a harmful nonmetallic inclusion existing in the spring is less than 20 μm or 15 μm or less,

condition Y: controlling the hardness of the matrix at a depth in the range of 0.2 mm to 0.5 mm inclusive from the spring surface in the range between Hv 520 and 630 inclusive when the size of a harmful nonmetallic inclusion existing in the spring can be controlled to 10 μm or less, the steel types (1) to (4) being as follows:

(1) a steel type containing as essential components C: 0.50 to 0.80%, Si: 1.20 to 2.5%, Mn: ≤1.20%, and Cr: ≤1.80% and iron and impurities as the remainder, including a steel type with one or two kinds of V: 0.03 to 0.60% and/or Nb: 0.02 to 0.20% added thereto;

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(2) a steel type containing one or more kinds of Ni: 0.5% or less and/or Co: 3.0% or less in addition to the steel type (1);

(3) a steel type containing W: 0.5% or less and/or Mo: 0.6% or less and/or Al: 0.5% or less in addition to the steel type (1) or (2); and

(4) a steel type containing C: 0.05% or less, Si: 0.8% or less, Mn: 0.8% or less, Ni: 16 to 26%, Ti: 0.2 to 1.6%, Al: 0.4% or less, Co: 8.5% or less, Mo: 5.5% or less, Nb: 0.6% or less, wherein in addition to the above, 0.1% or less of B, Zr, and/or Ca may be added, and unavoidable impurities and iron as the remainder, wherein the unit of the chemical components is all mass percent.

9. (Original) A steel spring excellent in fatigue strength, produced using any of the steel types (1) to (3) in claim 8, by quenching and tempering, so as to have a higher tensile strength than a JIS SWOSC-V oil tempered wire for valve springs depending on the wire diameter, forming into a spring, and then annealing at low temperature for removal of its residual stress, or by quenching and tempering after spring formation so as to have a higher tensile strength or hardness than a JIS SWOSC-V oil tempered wire for valve springs, or produced using the steel type (4) in claim 8 by performing solution treatment, cold wiredrawing or rolling, forming into a spring, aging, and quality-adjusting so that the tensile strength be 1900 MPa or more, being followed by the steps according to claim 4, wherein the spring has residual stress near the surface layer in the range between more than 1100 Mpa and 1700 MPa inclusive, the surface hardness is in the range of Hv 600 and Hv 800 inclusive, and when the hardness at a depth of 0.2 mm to 0.5 mm from the surface is in the range of Hv 580 to 630, the size of nonmetallic

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inclusions are less than 10 μm or less, and when the hardness at a depth of 0.2 mm to 0.5 mm from the surface is in the range between Hv 520 inclusive and less than Hv 580, the size of nonmetallic inclusions are 15 μm or less or less than 20 μm.

10. (Original) A spring according to claim 9, wherein the fatigue limit of the spring satisfies the following:

at a repeated stress of $\tau m \pm \tau a$, and 5×10^7 times of repetition,

$\tau a \geq 470 + x/5$ ...-----(2)

when $\tau m = 690 - x$,

where x: 0 to 183, and unit: MPa.

11. (Original) A spring made of cold drawn or warm drawn piano wire, low-alloy steel wire for spring superior in warm creep resistance to the piano wire, or similar steel wire, mainly composed of fine pearlite structure, having the wire diameter in the case of circular cross-section wire, the mean diameter or the mean thickness in the case of the noncircular cross-section wire of 1.5 mm or more, produced by subjecting to low temperature annealing for removal of the residual stress after forming into a spring, projecting hard metal particles having diameter of 0.2 to 0.9 mm, and then projecting a number of fine metal particles having a mean diameter of all particles of 65 μm or less, a mean diameter of each particle of 10 to 80 μm, spherical or near spherical shape having no square portions, specific gravity of 7.0 to 9.0, and hardness in the range of Hv 350 and 1100 inclusive at velocity of 50 to 160 m/sec, while controlling temperature to be low enough to cause work hardening in the near surface layer but not to cause

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recovery/recrystallization, and having compression residual stress of 550 MPa or more in the iron matrix of the surface layer by X-ray method and a fatigue limit of:

at a repeated stress of $\tau m \pm \tau a$, and 5×10^7 times of repetition,

$\tau a \geq 422 + x/5$ ... (3)

when $\tau m = 690 - x$,

where, unit: MPa, and x: 0 to 140.

12. (Original) A spring made of a normal JIS SWOSC-V oil tempered wire for valve springs produced by subjecting to low-temperature annealing for removal of residual stress after formation into a spring, projecting hard metal particles having diameter of 0.2 to 0.9 mm, and then projecting a number of fine metal particles having a mean diameter of all particles of 65 μm or less, a mean diameter of each particle of 10 to 80 μm, a spherical or near spherical shape having no square portions, a specific gravity of 7.0 to 9.0, and a hardness in the range of Hv 500 and 1100 inclusive at a velocity of 50 to 160 m/sec. while controlling a temperature to be low enough to cause work hardening in the near surface layer but not to cause recovery/recrystallization, to obtain compression residual stress measured by X-ray method of 900 MPa or more in the near surface layer, hardness at the depth of 0.2 to 0.5 mm from the surface of Hv 520 to 600, sizes of nonmetallic inclusions of 15 μm or less, and the fatigue limit of:

at a repeated stress of $\tau m \pm \tau a$, and 5×10^7 times of repetition,

$\tau a \geq 440 + x/5$ ... (4)

when $\tau m = 690 - x$,

where, unit: MPa, and x: 0 to 208.

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13. (Original) A sheet spring or wire spring with excellent fatigue strength, of which hardness at the surface layer before shot-peening is Hv 400 to 750, obtained by being projected by metal particles, each of which is characterized by the hardness of Hv 350 to 1100, the mean diameter of 10 to 80 μm, spherical or near spherical shape with no square portions and a specific gravity of 7.0 to 9.0, with the mean diameter of the largest particle and the mean diameter of all particles to be 80 μm and 65 μm, respectively and preferably 75 μm and 50 μm, respectively, at a collision velocity of 50 to 160 m/sec while controlling the projection so as to cause work hardening but not to cause recovery/recrystallization.

14. (Previously Presented) The spring surface treatment method of claim 2, wherein the metal particles in step (A) are iron-based particles.

15. (Previously Presented) The spring surface treatment method of claim 2, wherein the metal particles in step (A) have a mean diameter of all particles of 65 μm or less.

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